

PRODUCTION-ENHANCING COMPLETION METHODS

1. Field of the Invention.

[001] The present invention relates to improved methods for completing well bores along producing zones and, more particularly, to methods for completing well bores along producing zones while controlling formation sands and increasing surface area available for production.

2. Description of the Prior Art.

[002] One completion method commonly used along a producing zone of a well bore involves gravel packing. Such gravel packing treatments are used, *inter alia*, to reduce the migration of unconsolidated formation particulates into the well bore. One common gravel packing operation involves placing a gravel pack screen in the well bore and packing the surrounding annulus between the screen and the well bore with particulates referred to as "gravel" that have a specific size designed to prevent the passage of formation sand. The gravel pack screen is generally a filter assembly used to support and retain the gravel placed during gravel pack operations. A wide range of sizes and screen configurations are available to suit the characteristics of the gravel pack sand used. Similarly, a wide range of sizes of gravel is available to suit the characteristics of the unconsolidated or poorly consolidated particulates in the subterranean formation. The resulting structure presents a barrier to migrating sand from the formation while still permitting fluid flow. When installing the gravel pack, the gravel is carried to the formation in the form of a slurry by mixing the gravel with a transport fluid. Gravel packs act, *inter alia*, to stabilize the formation while causing minimal impairment to well productivity. The gravel, *inter alia*, acts to prevent the particulates from occluding the screen or migrating with the produced fluids, and the screen, *inter alia*, acts to prevent the gravel from entering the production tubing. While gravel packs have been successfully used to control the migration of formation sands, their placement reduces the available diameter of a well bore due to the physical size of the screen and the resulting gravel annulus.

[003] The screen assemblies used in gravel packing operations may also be used independently to control unconsolidated formation sands. Some of the early screen technology dictated that the screens had to be small enough to pass through the smallest diameter of the well bore on the way to its desired placement location where the diameter of the well bore may actually be larger. Developments in technology have lead to expandable screens such that a relatively small size or small diameter screen may be placed in a desired location along the well bore and then expanded to accommodate the actual size of the well bore at the point of placement.

[004] Another completion method along a producing zone of a well bore, known as hydrajetting, involves the use of hydraulic jets, *inter alia*, to increase the permeability and production capabilities of a formation. In a common hydrajetting operation, a hydrajetting tool having at least one fluid jet forming nozzle is positioned adjacent to a formation to be fractured, and fluid is then jetted through the nozzle against the formation at a pressure sufficient to form a cavity, or slot therein to fracture the formation by stagnation pressure in the cavity. Because the jetted fluids would have to flow out of the slot in a direction generally opposite to the direction of the incoming jetted fluid, they are trapped in the slot and create a relatively high stagnation pressure at the tip of a cavity. This high stagnation pressure often causes a microfracture to be formed that extends a short distance into the formation. That microfracture may be further extended by pumping a fluid into the well bore to raise the ambient fluid pressure exerted on the formation while the formation is being hydrajetted. Such a fluid in the well bore will flow into the slot and fracture produced by the fluid jet and, if introduced into the well bore at a sufficient rate and pressure, may be used to extend the fracture an additional distance from the well bore into the formation.

SUMMARY OF THE INVENTION

[005] The present invention relates to improved methods for completing well bores along producing zones and, more particularly, to methods for completing well bores along producing zones while controlling formation sands and increasing surface area available for production.

[006] Some embodiments of the present invention provide methods of controlling the migration of formation sand in a well bore and increasing surface area for well production comprising the steps of hydrajetting at least one slot into a zone along a well bore; and, placing a consolidation material comprising particulates into the slot.

[007] Other embodiments of the present invention provide methods of increasing production from a zone along a well bore comprising the steps of hydrajetting at least one slot into the zone along the well bore; and, placing a consolidation material comprising particulates into the slot.

[008] Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments which follows.

DESCRIPTION OF PREFERRED EMBODIMENTS

[009] The present invention relates to improved methods for completing well bores along producing zones and, more particularly, to methods for completing well bores along producing zones while controlling formation sands and increasing surface area available for production.

[010] In some embodiments of the methods of the present invention an isolated zone along a well bore is hydrajetted to produce at least one slot, and a consolidating material comprising a proppant is forced into the slot.

[011] Hydrajetting basically involves the use of a tool such as those described in U.S. Patent Nos. 5,765,642, 5,494,103, and 5,361,856, the relevant portions of which are herein incorporated by reference, to create a path, known as a "slot," into the formation from the well bore. In some embodiments of the present invention, the hydrajetting tool is used to create slots substantially uniformly around the well bore circumference. Forcing the consolidating material comprising a proppant into the slot causes the slot to continue to grow further into the formation.

[012] Consolidating materials suitable for use in the methods of the present invention include resinous materials and tackifying materials. The consolidation material comprising proppant not only acts, *inter alia*, to maintain the integrity of the hydrajetted slots; it may also act as a sand control treatment by controlling the migration of formation sands.

[013] Where a resin consolidation material is used, it may be a curable resin. Resin-type consolidation materials aid in the consolidation of the proppant and formation sands. Such consolidation may be desirable to reduce proppant flow-back. Suitable such resin consolidation materials include, but are not limited to, two-component epoxy-based resins, furan-based resins, phenolic-based resins, high-temperature (HT) epoxy-based resins, and phenol/phenol formaldehyde/furfuryl alcohol resins.

[014] Selection of a suitable resin consolidation material may be affected by the temperature of the subterranean formation to which the fluid will be introduced. By way of example, for subterranean formations having a bottom hole static temperature ("BHST") ranging from about 60°F to about 250°F, two-component epoxy-based resins comprising a hardenable resin component and a hardening agent component containing specific hardening agents may be preferred. For subterranean formations having a BHST ranging from about 300°F to about 600°F, a furan-based resin may be preferred. For subterranean formations having a BHST

ranging from about 200°F to about 400°F, either a phenolic-based resin or a one-component HT epoxy-based resin may be suitable. For subterranean formations having a BHST of at least about 175°F, a phenol/phenol formaldehyde/furfuryl alcohol resin may also be suitable.

[015] One resin consolidation material suitable for use in the methods of the present invention is a two-component epoxy based resin comprising a hardenable resin component and a hardening agent component. The hardenable resin component is comprised of a hardenable resin and an optional solvent. The solvent may be added to the resin to reduce its viscosity for ease of handling, mixing and transferring. It is within the ability of one skilled in the art with the benefit of this disclosure to determine if and how much solvent may be needed to achieve a viscosity suitable to the subterranean conditions. Factors that may affect this decision include geographic location of the well and the surrounding weather conditions. An alternate way to reduce the viscosity of the liquid hardenable resin is to heat it. This method avoids the use of a solvent altogether, which may be desirable in certain circumstances. The second component is the liquid hardening agent component, which is comprised of a hardening agent, a silane coupling agent, a surfactant, an optional hydrolyzable ester for, *inter alia*, breaking gelled fracturing fluid films on the proppant particles, and an optional liquid carrier fluid for, *inter alia*, reducing the viscosity of the liquid hardening agent component. It is within the ability of one skilled in the art with the benefit of this disclosure to determine if and how much liquid carrier fluid is needed to achieve a viscosity suitable to the subterranean conditions.

[016] Examples of liquid hardenable resins that can be used include, but are not limited to, organic resins such as bisphenol A-epichlorohydrin resins, polyepoxide resins, novolak resins, polyester resins, phenol-aldehyde resins, urea-aldehyde resins, furan resins, urethane resins, glycidyl ethers and mixtures thereof. The liquid hardenable resin used is included in the liquid hardenable resin component in an amount sufficient to consolidate particulates. In some embodiments of the present invention, the resin used is included in the liquid hardenable resin component in the range of from about 70% to about 100% by weight of the liquid hardenable resin component.

[017] Any solvent that is compatible with the hardenable resin and achieves the desired viscosity effect is suitable for use in the present invention. Preferred solvents are those having high flash points (most preferably about 125°F) because of, *inter alia*, environmental factors. As described above, use of a solvent in the hardenable resin composition is optional but may be

desirable to reduce the viscosity of the hardenable resin component for a variety of reasons including ease of handling, mixing, and transferring. It is within the ability of one skilled in the art with the benefit of this disclosure to determine if and how much solvent is needed to achieve a suitable viscosity. Solvents suitable for use in the present invention include, but are not limited to, butylglycidyl ethers, dipropylene glycol methyl ethers, dipropylene glycol dimethyl ethers, dimethyl formamides, diethyleneglycol methyl ethers, ethyleneglycol butyl ethers, diethyleneglycol butyl ethers, propylene carbonates, methanols, butyl alcohols, d'limonene and fatty acid methyl esters.

[018] Examples of the hardening agents that can be used in the liquid hardening agent component of the two-component consolidation fluids of the present invention include, but are not limited to, amines, aromatic amines, polyamines, aliphatic amines, cyclo-aliphatic amines, amides, polyamides, 2-ethyl-4-methyl imidazole and 1,1,3-trichlorotrifluoroacetone. Selection of a preferred hardening agent depends, in part, on the temperature of the formation in which the hardening agent will be used. By way of example and not of limitation, in subterranean formations having a temperature from about 60°F to about 250°F, amines and cyclo-aliphatic amines such as piperidine, triethylamine, N,N-dimethylaminopyridine, benzylidemethylamine, tris(dimethylaminomethyl) phenol, and 2-(N₂N-dimethylaminomethyl)phenol are preferred with N,N-dimethylaminopyridine most preferred. In subterranean formations having higher temperatures, 4,4-diaminodiphenyl sulfone may be a suitable hardening agent. The hardening agent used is included in the liquid hardening agent component in an amount sufficient to consolidate particulates. In some embodiments of the present invention, the hardening agent used is included in the liquid hardenable resin component in the range of from about 40% to about 60% by weight of the liquid hardening agent component.

[019] The silane coupling agent may be used, *inter alia*, to act as a mediator to help bond the resin to the sand surface. Examples of silane coupling agents that can be utilized in the liquid hardening agent component of the two-component consolidation fluids of the present invention include, but are not limited to, n-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane. The silane coupling agent used is included in the liquid hardening agent component in an amount capable of sufficiently bonding the resin to the particulate. In some embodiments of the present invention, the silane coupling agent used is included in the liquid

hardenable resin component in the range of from about 0.1% to about 3% by weight of the liquid hardening agent component.

[020] Any surfactant compatible with the liquid hardening agent may be used in the present invention. Such surfactants include, but are not limited to, ethoxylated nonyl phenol phosphate esters, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and alkyl phosphonate surfactants. The mixtures of one or more cationic and nonionic surfactants are described in U.S. Patent No. 6,311,733, the relevant disclosure of which is incorporated herein by reference. A C₁₂ – C₂₂ alkyl phosphonate surfactant is preferred. The surfactant or surfactants utilized are included in the liquid hardening agent component in an amount in the range of from about 2% to about 15% by weight of the liquid hardening agent component.

[021] Use of a diluent or liquid carrier fluid in the hardenable resin composition is optional and may be used to reduce the viscosity of the hardenable resin component for ease of handling, mixing and transferring. It is within the ability of one skilled in the art, with the benefit of this disclosure, to determine if and how much liquid carrier fluid is needed to achieve a viscosity suitable to the subterranean conditions. Any suitable carrier fluid that is compatible with the hardenable resin and achieves the desired viscosity effects is suitable for use in the present invention. The liquid carrier fluids that can be utilized in the liquid hardening agent component of the two-component consolidation fluids of the present invention preferably include those having high flash points (most preferably above about 125°F). Examples of liquid carrier fluids suitable for use in the present invention include, but are not limited to, dipropylene glycol methyl ethers, dipropylene glycol dimethyl ethers, dimethyl formamides, diethyleneglycol methyl ethers, ethyleneglycol butyl ethers, diethyleneglycol butyl ethers, propylene carbonates, d'limonene and fatty acid methyl esters.

[022] Another resin suitable for use in the methods of the present invention are furan-based resins. Suitable furan-based resins include, but are not limited to, furfuryl alcohol resins, mixtures furfuryl alcohol resins and aldehydes, and a mixture of furan resins and phenolic resins. A furan-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the furan-based consolidation fluids of the present invention include, but are not limited to 2-butoxy ethanol, butyl acetate, and furfuryl acetate.

[023] Still another resin suitable for use in the methods of the present invention are phenolic-based resins. Suitable phenolic-based resins include, but are not limited to, terpolymers of phenol, phenolic formaldehyde resins, and a mixture of phenolic and furan resins. A phenolic-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the phenolic-based consolidation fluids of the present invention include, but are not limited to butyl acetate, butyl lactate, furfuryl acetate, and 2-butoxy ethanol.

[024] Another resin suitable for use in the methods of the present invention is a HT epoxy-based resin. Suitable HT epoxy-based components include, but are not limited to, bisphenol A-epichlorohydrin resins, polyepoxide resins, novolac resins, polyester resins, glycidyl ethers and mixtures thereof. An HT epoxy-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use with the HT epoxy-based resins of the present invention are those solvents capable of substantially dissolving the HT epoxy-resin chosen for use in the consolidation fluid. Such solvents include, but are not limited to, dimethyl sulfoxide and dimethyl formamide. A co-solvent such as a dipropylene glycol methyl ether, dipropylene glycol dimethyl ether, dimethyl formamide, diethylene glycol methyl ether, ethylene glycol butyl ether, diethylene glycol butyl ether, propylene carbonate, d'limonene and fatty acid methyl esters, may also be used in combination with the solvent.

[025] Yet another resin consolidation material suitable for use in the methods of the present invention is a phenol/phenol formaldehyde/furfuryl alcohol resin comprising from about 5% to about 30% phenol, from about 40% to about 70% phenol formaldehyde, from about 10 to about 40% furfuryl alcohol, from about 0.1% to about 3% of a silane coupling agent, and from about 1% to about 15% of a surfactant. In the phenol/phenol formaldehyde/furfuryl alcohol resins suitable for use in the methods of the present invention, suitable silane coupling agents include, but are not limited to, n-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane. Suitable surfactants include, but are not limited to, an ethoxylated nonyl phenol phosphate ester, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and an alkyl phosphonate surfactant.

[026] A tackifying material may be also used in the methods and compositions of the present invention. Compounds suitable for use as a tackifying compound in the present invention comprise substantially any compound that, when in liquid form or in a solvent

solution, will form a non-hardening, sticky coating upon particulates. A particularly preferred group of tackifying compounds comprise polyamides that are liquids or in solution at the temperature of the subterranean formation such that the polyamides are, by themselves, non-hardening when present on the particulates introduced into the subterranean formation. A particularly preferred product is a condensation reaction product comprised of commercially available polyacids and a polyamine. Such commercial products include compounds such as mixtures of C₃₆ dibasic acids containing some trimer and higher oligomers and also small amounts of monomer acids that are reacted with polyamines. Other polyacids include trimer acids, synthetic acids produced from fatty acids, maleic anhydride and acrylic acid and the like. Such acid compounds are commercially available from companies such as Witco Corporation, Union Camp, Chemtall, and Emery Industries. The reaction products are available from, for example, Champion Technologies, Inc. and Witco Corporation. Additional compounds which may be utilized as tackifying compounds include liquids and solutions of, for example, polyesters, polycarbonates and polycarbamates, natural resins such as shellac and the like. Suitable tackifying compounds are described in U.S. Patent Number 5,853,048 issued to Weaver, et al. and U.S. Patent Number 5,833,000 issued to Weaver, et al., the disclosures of which are herein incorporated by reference.

[027] Any particulate suitable for use in subterranean applications is suitable for use in the compositions and methods of the present invention. For instance, natural sand, ground walnut hulls, man-made proppants, including bauxite, ceramics, polymeric materials, or the like are suitable. Suitable sizes range from 4 to 100 U.S. mesh, but are preferably in the range of 10 to 60 US mesh. The particulate material may be combined with the consolidation material either on-the-fly or may be combined in ahead of schedule and brought to the well site.

[028] In some embodiments of the present invention, once the hydrajetting and placement of the consolidating material is complete, an expandable screen may be placed in the well bore. One skilled in the art, with the benefit of this disclosure, will be able to determine when it is advantageous to use such an expandable screen. For example, the isolated well bore section may be either cased or uncased. Where the present invention is used on an uncased isolated zone, an expandable screen may be necessary used to control the formation sands surrounding the isolated zone. Moreover, as a tackifying material does not harden and cannot be guaranteed to permanently consolidate particulates such as proppant, where the consolidating

fluid chosen is a tackifying material an expandable screen may be necessary to control not only the migration of formation sands, but also the migration of proppant.

[029] Where an expandable screen is used, its openings should be sized based on its application. For example, when used in an uncased well bore, the openings in the expandable screen should be sized based on the size of the proppant and the size of the formation sands to be controlled. Where an expandable screen is used in a cased well bore, only the size of the proppant need be considered.

[030] One embodiment of a method of the present invention provides a method of controlling the migration of formation sand in a well bore and increasing formation permeability comprising the steps of isolating a zone of interest along a well bore, hydrajetting at least one slot in the zone of interest, and contemporaneously filling the slot with a consolidation material and proppant.

[031] Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit and scope of this invention as defined by the appended claims.